



## Chapter 23 – Liquefied Gases

A liquefied gas is a gaseous substance at ambient temperature and pressure, that is liquefied by pressurisation or refrigeration and sometimes a combination of the two. Virtually all liquefied gases are hydrocarbons and flammable in nature. Liquefaction compresses the gas into volumes suited to international carriage. The principal gas cargoes are liquefied natural gas (LNG) (see Chapter 24), liquefied petroleum gas (LPG), and a variety of petrochemical gases, each associated with specific hazards. By regulation, all liquefied gases when transported in bulk must be carried on a gas carrier, as defined by the IMO. The IMO's Gas Codes (see Section 23.3) provide a list of safety precautions and design features required for each product.

### 23.1 LPG

LPG covers butane or propane or a mixture of the two. The main use for these products varies from country to country, but sizeable volumes are used as power station or refinery fuels. However, LPG is also sought after as a bottled cooking gas and it can form a feedstock at chemical plants. It is also used as an aerosol propellant and is added to gasoline as a vapour pressure enhancer. LPG may be carried in either a pressurised or refrigerated state. Occasionally, it may be carried in a special type of carrier known as a semi-pressurised ship. When fully refrigerated, butane is carried at minus 5°C (–5°C) and propane at minus 42°C (–42°C). The low carriage temperature required for propane introduces the need for special low temperature (LT) steels.

## 23.2 Chemical and Other Gases

Ammonia is one of the most common chemical gases and it is carried worldwide in large volumes, mainly for agricultural purposes. It has particularly toxic qualities and requires great care during handling and carriage.

Another important liquefied gas is ethylene. Very sophisticated ships are available for this product as carriage temperatures are minus 104°C (–104°C) and onboard systems require a high degree of expertise. Within this group, a subset of highly specialised ships is able to carry multigrades simultaneously.

The recent exploitation of shale gas has brought an increase in LPG and ethane production, as by-products. Ethane may be used as an alternative to naphtha or LPG as a feedstock for the chemical industry. Liquefied ethane, with a temperature close to minus 89°C (–89°C) at atmospheric pressure, has typically been shipped in small ethylene/ethane carriers. The design characteristics of the cargo containment system for the ships in this trade is in the region of 27,500 to 35,000 m<sup>3</sup>. The economies of scale needed for a profitable global trade typically require ethane to be shipped in large volumes. The largest VLEC in the world, '*Pacific Ineos Belstaff*', has a capacity of 99,000 m<sup>3</sup> and was built at the end of 2021. It is designed with Type B tanks which can carry LPG, ethylene and ethane.

Significant in the design and operation of all gas carriers is that methane (the main constituent of LNG) vapour is lighter than air, while LPG vapours are heavier than air. For this reason, the current gas carrier regulations allow only methane to be used as a propulsion fuel, with any minor gas seepage in engine spaces being naturally ventilated. With the adoption in January 2017 by the IMO of the *International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels* (IGF Code) (Reference 44), it has become increasingly likely that LPG will be used as propulsion fuel on future vessels. It is a sulphur-free fuel type, which makes compliance with the latest emission regulations feasible.

The principal hydrocarbon gases such as butane, propane and methane are non-toxic in nature. A comparison of the relative hazards of oils and gases is provided in Table 23.1.

Hazard	Gases		Oils	
	LNG	LPG	Gasoline	Fuel oil
Toxic	No	No	Yes	Yes
Carcinogenic	No	No	Yes	Yes
Asphyxiant	Yes (in confined spaces)	Yes (in confined spaces)	No	No
Others	Low temperature	Moderately low temperature	Eye irritant, narcotic, nausea	Eye irritant, narcotic, nausea
Flammability limits in air (%)	5 to 15	2 to 10	1 to 6	Not applicable
Storage pressure	Atmospheric	Often pressurised	Atmospheric	Atmospheric
Behaviour if spilt	Evaporates forming a visible 'cloud' that disperses readily and is non-explosive, unless contained	Evaporates forming an explosive vapour cloud	Forms a flammable pool which, if ignited, would burn with explosive force; environmental clean-up may be required	Forms a flammable pool; environmental clean-up is required

Table 23.1: Comparative hazards of some liquefied gases and oils.

### 23.2.1 The Liquefied Gas Fleet

The fleet of liquefied gas carriers of over 1,000 m<sup>3</sup> capacity can be divided into the following types:

- Pressurised LPG carriers
- semi-refrigerated LPG carriers (including ethylene)
- fully refrigerated LPG carriers
- LNG carriers
- LNG FSRUs.

Chapter 24 describes the liquefied natural gas (LNG) carrier in more detail.

The sealed nature of liquefied gas cargoes, in tanks completely segregated from oxygen or air, virtually excludes any possibility of a tank explosion. However, the idea of the unsafe ship lingers, and some administrations and Port State Control (PSC) organisations tend to target gas carriers for special inspection whenever they enter harbour.

However, serious accidents related to gas carrier cargoes have been few and the gas carrier's safety record is acknowledged as an industry leader. As an illustration of the robustness of gas carriers, when the *'Gaz Fountain'* was hit by rockets during the Iran/Iraq War in the 1980s, despite penetration of the containment system with huge jet fires, the fires were successfully extinguished and the ship, together with most of the cargo, was salvaged.

The relative safety of the gas carrier is due to a number of features. One such, almost unique to the class, is that cargo tanks are always kept under positive pressure (sometimes just a small overpressure) and this prevents air entering the cargo system. This means that only liquid cargo or vapour can be present, so a flammable atmosphere cannot exist in the cargo system. In addition, all large gas carriers use a closed loading system with no venting to atmosphere, and a vapour return line (VRL) to the shore is often fitted and used where required.

In 2016, the world's first compressed natural gas (CNG) carrier was launched.

### 23.3 Regulation of Gas Carrier Design

The regulations for the design and construction of gas carriers stem from practical ship designs codified by the IMO. However, all new ships (from June 1986) are built to the *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (the IGC Code) (Reference 45). This code also defines cargo properties and documentation provided to the ship (the Certificate of Fitness for the Carriage of Liquefied Gases in Bulk) and shows the cargo grades the ship can carry. In particular, this takes into account temperature limitations imposed by the metallurgical properties of the materials making up the containment and piping systems. It also considers the reactions between various gases and the elements of construction, not only for tanks but also related to pipeline and valve fittings. The IGC Code, adopted by the IMO in 2014, applies to all new ships built (having their keel laid) after 1<sup>st</sup> July 2016. The latest 2016 edition includes corrections and a supplement added in 2019.

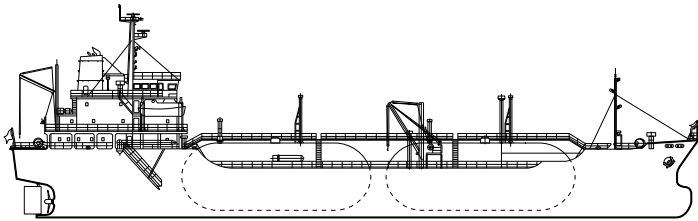
When the IGC Code was produced, an intermediate code was also developed by the IMO – the *Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (the GC Code) (Reference 46). This covers ships built between 1977 and 1986.

Gas carriers were in existence before IMO codification and ships built before 1977 are defined as 'existing ships' within the meaning of the rules. To cover these ships, a voluntary code was devised, again by the IMO – the *Code for Existing Ships Carrying Liquefied Gases in Bulk* (the EGC Code) (Reference 47). Despite its voluntary status, virtually all ships remaining in the fleet that are of this age, and because of longevity programmes there are still quite a number, have certification in accordance with the EGC Code.

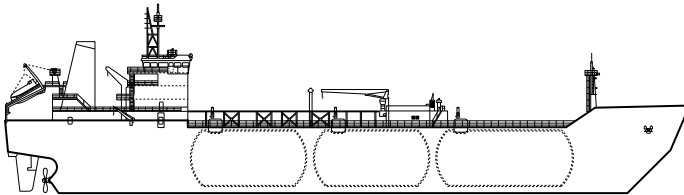
## 23.4 Design of Gas Carriers

Cargo carriage in the pressurised fleet comprises double cargo containment. All other gas carriers are built with a double-hull structure and the distance of the inner hull from the outer is defined in the Gas Codes. This spacing introduces a vital safety feature to mitigate the consequences of collision and grounding.

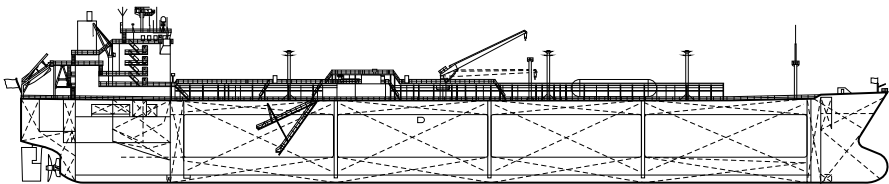
A principal feature of gas carrier design is therefore double containment and an internal hold. The cargo tanks, more generally referred to as the cargo containment system, are installed in the hold, often as a completely separate entity from the ship, ie not part of the ship's structure or its strength members. This is a distinctive difference between gas carriers and oil tankers or chemical carriers.



a) Coastal LPG carrier with cylindrical tanks



b) Semi-pressurised LPG carrier



c) LPG carrier with Type A tanks

**Figure 23.1: Gas carrier types.**

Cargo tanks may be of the independent self-supporting type or of a membrane design. Self-supporting tanks are defined in the IGC Code as being of Type A, Type B or Type C. Type A containment comprises box-shaped or prismatic tanks (ie shaped to fit the hold). Type B comprises tanks where fatigue life and crack propagation analyses have shown improved characteristics. Such tanks are usually spherical but occasionally may be of prismatic types. Type C tanks are pure pressure vessels, often spherical or cylindrical, but sometimes bi-lobe in shape to minimise broken stowage.

The fitting of one system in preference to another tends towards particular trades. For example, Type C tanks are suited to small volume carriage. They are therefore found most often on coastal or regional craft. Large international LPGCs will normally be fitted with Type A tanks.

Type B tanks and tanks following membrane principles are found mainly within the LNG fleet and will be discussed in Chapter 24.

### 23.4.1 The Pressurised Fleet

Figure 23.1a) shows a small fully pressurised LPGC. Regional and coastal cargoes are often carried in such craft, with the cargo fully pressurised at ambient temperature. The tanks are built as pure pressure vessels without the need for any extra metallurgical consideration appropriate to colder temperatures. Design pressures are usually for propane (about 20 bar) as this form of LPG has the highest vapour pressure at ambient temperature. The ship design comprises the outer hull and an inner hold containing the pressure vessels. These rest in saddles built into the ship's structure. Double bottoms and other spaces act as water ballast tanks and, if problems are to develop with age, the ballast tanks are prime candidates. These ships are the most numerous class, comprising approximately 40% of the fleet. They are relatively simple in design but strong in construction. Cargo operations involve cargo transfer by flexible hose and, in certain areas, ship to ship transfer operations from larger refrigerated ships operating internationally are commonplace.



Figure 23.2: Pressurised LPGC with cylindrical tanks.

### 23.4.2 The Semi-pressurised Fleet

In these ships, sometimes referred to as semi-refrigerated, the cargo is carried in pressure vessels that are usually bi-lobe in cross-section, designed for operating pressures of up to 7 bar. The tanks are constructed of special grade steel suitable for the cargo carriage temperature and the tanks are insulated to minimise heat input to the cargo. The cargo boils off causing generation of vapour, which is reliquefied by refrigeration and returned to the cargo tanks. The required cargo temperature and pressure are maintained by the reliquefaction plant.

These ships are usually larger than the fully pressurised types and have cargo capacities of up to about 20,000 m<sup>3</sup>. As with the fully pressurised ship, the cargo tanks

are of pressure vessel construction and similarly located well inboard of the ship's side while protected by double-bottom ballast tanks. This arrangement results in a very robust and inherently buoyant ship.



**Figure 23.3: Semi-pressurised LPGC.**

### 23.4.3 The Ethylene Fleet

Ethylene is the primary building block of the petrochemicals industry and is used in the production of polyethylene, ethylene dichloride, ethanol, styrene, glycols and many other products. Storage is usually as a fully refrigerated liquid at minus  $104^{\circ}\text{C}$  ( $-104^{\circ}\text{C}$ ).

Ships designed for ethylene carriage also fall into the semi-pressurised class. They are relatively few in number but are among the most sophisticated ships afloat. In the more advanced designs, they can carry several grades. Typically, this range can extend to ethane, LPG, ammonia, propylene butadiene and vinyl chloride monomer (VCM), all featuring on their certificate of fitness. To aid in this process, several independent cargo systems coexist on board to avoid cross contamination of the cargoes, particularly for the reliquefaction process.

The ships range in size from about 2,000 to 15,000  $\text{m}^3$ , although several larger ships now trade in ethylene. Ship design usually includes independent cargo tanks (Type C) and these may be cylindrical or bi-lobe in shape, constructed from stainless steel. An inert gas generator is provided to produce dry inert gas or dry air. The generator is used for inerting and for dehydration of the cargo system and the interbarrier spaces during the voyage, when condensation can occur on cold surfaces creating unwanted build-ups of ice. Deck tanks are normally provided for changeover of cargoes.

The hazards associated with the cargoes involved arise from the temperature, toxicity and flammability. The safety of ethane carriers is critical, requiring good management and rigorous personnel training.

Ethane carriers may be seen as a subset of the ethylene fleet and ethane can be carried by ships designed to carry ethylene. The new VLEC class (see Section 23.2) are constructed with a reinforced membrane cargo containment system, similar to that used in LNG carriers.

#### 23.4.4 The Fully Refrigerated Fleet



**Figure 23.4: Fully refrigerated LPGC.**

These are generally large ships, up to about 85,000 m<sup>3</sup> cargo capacity, with those above 70,000 m<sup>3</sup> designated as VLGCs. Many in the intermediate range (30,000 to 60,000 m<sup>3</sup>) are suitable for carrying the full range of hydrocarbon liquid gas, from butane to propylene, and may be equipped to also carry chemical liquid gases such as ammonia. Cargoes are carried at near ambient pressure and at temperatures down to minus 48°C (-48°C). Reliquefaction plants are fitted (to manage boil-off) with a substantial reserve plant capacity provided. The cargo tanks do not have to withstand high pressures and are, therefore, generally of the freestanding prismatic type. The tanks are robustly stiffened internally and constructed of special low temperature resistant steel.

All ships have substantial double-bottom spaces and some have side ballast tanks. In all cases, the cargo tanks are protectively located inboard. The ship's structure surrounding or adjacent to the cargo tanks is also of special grade steel and this forms a secondary barrier to safely contain any cold cargo should it leak from the cargo tanks.

All cargo tanks, whether of the pressure vessel type or rectangular, are provided with safety relief valves amply sized to relieve boil-off in the absence of reliquefaction and even in conditions of surrounding fire.





Figure 23.5: LNG carrier with membrane tanks.

## 23.5 Crew Training and Numbers

The IMO has laid down a series of training standards for gas carrier crews that are additional to normal certification. These dangerous cargo endorsements are detailed in the STCW Convention (Reference 48). Courses are divided into the basic course for junior officers and the advanced course for senior officers. IMO rules require a certain amount of onboard gas experience, particularly at senior ranks, before taking on a responsible role or before progressing to the next rank.

In addition to the official certification for hazardous cargo endorsements, a number of colleges operate special courses for gas cargo handling. While this provides for a well-trained and highly knowledgeable environment, the continued growth in the fleet currently strains manpower resources and training schedules. To mitigate these pressures, in addition to the STCW requirements, the Society of International Gas Tanker and Terminal Operators (SIGTTO) provides guidance on competency standards and experience levels for officers serving on gas ships. While small gas carriers normally operate at minimum crew levels, on larger carriers it is normal to find increased crewing levels over and above the minimum required by the ship's manning certificate.

## 23.6 Gas Carriers and Port Operations

Terminals undergo careful risk analysis at the time of construction, helping to ensure that the location and size of maximum credible spill scenarios are identified and that suitable precautions, including appropriate safety distances, are established between operational areas and local populations.

Risk analysis of cargo transfer operations often identifies the cargo manifold as the area most likely to be the source of the maximum credible spill. This is controlled by a number of measures. Primarily, as for all large oil tankers, gas carriers should be held firmly in position while handling cargo, and mooring management should be of a high calibre. Mooring ropes should be well managed throughout loading and discharging.

Safe mooring is often the subject of computerised mooring analysis, particularly for new ships arriving at new ports, helping to ensure a sensible mooring array suited to the harshest conditions. An accident in the UK highlighted the consequences of a lack of such procedures when, in 1993, a 60,000 m<sup>3</sup> LPGC broke out from her berth in storm conditions. This was the subject of an official MCA/HSE inquiry, concluding that prior mooring analysis was vital to safe operations. The safe mooring principles attached to gas carriers are similar to those recommended for oil tankers (they are itemised in *Mooring Equipment Guidelines, 4<sup>th</sup> Edition* (MEG4) (Reference 49).

The need for such ships to be held firmly in position during cargo handling is due in part to the use of marine loading arms (MLAs) (see Figure 23.6) for cargo transfer. Such equipment is of limited reach in comparison to hoses, yet it provides the ultimate in robustness and simplicity in connection at the cargo manifold.



Figure 23.6: MLAs at cargo manifold (on an LNGC).

The use of MLAs for large gas carriers is common and is an industry recommendation. The use of hoses creates concerns over hose care and maintenance, and their proper layout and support during operations to prevent kinking and abrasion. In addition, accident statistics show that hoses have inferior qualities in comparison to MLAs. Perhaps the worst case of hose failure occurred in 1985 when a large LPGC was loading at Pajaritos, Mexico. In this incident, the hose burst and, in a short time, the resulting gas cloud ignited. The consequent fire and explosion impinged directly on three other ships in harbour and resulted in four deaths.



**Figure 23.7:** MLA quick connect/disconnect coupler (QC/DC).



**Figure 23.8:** MLA connection to manifold, showing double ball valve safety release.

As ships have grown in size, the installation of VRLs interconnecting ship and shore vapour systems has become more common for LPGCs (and is an integral part of the LNG system – see Chapter 24).

A feature common to both ship and shore is an emergency shutdown system (ESD). It is common to interconnect such systems so that, for example, an emergency on the ship will stop shore-based loading pumps or, conversely, an emergency at an

unloading terminal will stop the ship's cargo pumps. It is common for hard arms to be fitted with automatic detection and alarm systems to guard the operating envelope. A further refinement at some larger LPG terminals is to have the loading arms fitted with emergency release devices that allow the hard arms to automatically release with minimal loss of product before they reach the limits of the operating envelope. These devices are commonly referred to as emergency release couplings (ERCs).

## **23.7 Society of International Gas Tanker and Terminal Operators (SIGTTO)**

Valuable assistance in the preparation of these chapters has come from SIGTTO.

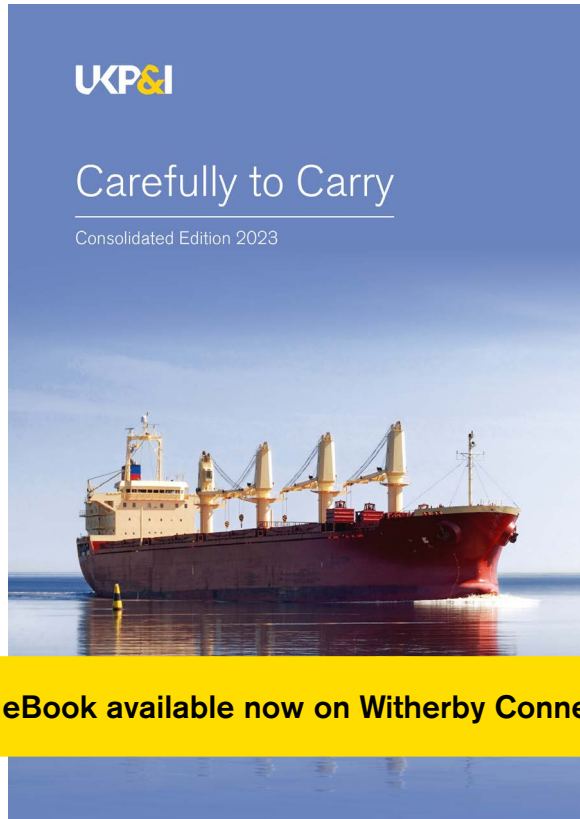
SIGTTO is the leading trade body in this field and has 213 members (December 2020), covering nearly 90% of the world's LNG fleet and 50% of the LPG fleet. SIGTTO members also control most of the terminals that handle these products.

SIGTTO's stated aim is to encourage the safe and responsible operation of liquefied gas tankers and marine terminals handling liquefied gas; to develop advice and guidance for best industry practice among its members and to promote criteria for best practice to all who have responsibilities for, or an interest in, the continuing safety of gas tankers and terminals.

Further details on activities and membership are available at [www.sigtto.org](http://www.sigtto.org)



**Price: £95**



**Full eBook available now on Witherby Connect**

This comprehensive publication, compiled by the UK P&I Club, details best practice for the carriage, loading and storage requirements of a wide range of cargoes. It also contains essential information on draught surveys and preparing cargo plans.

Outlining and expanding on all major international cargo regulations and guidelines, it also includes detailed checklists, information on draught surveys and guides to preparing cargo plans. Cargoes covered include timber, gas, grain, steel and other metals, bulk goods and refrigerated goods.